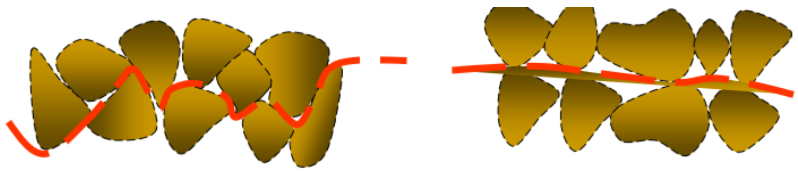
Shear Strength of Soil

One of the main roles of a civil engineer is to explore the ground conditions on which a structure is being built. If the soil fails then the structure being supported by it may also fail, so understanding the soil's properties is vital. The relevant properties can be established by taking soil samples on site and performing a series of tests, thus enabling engineers to design safely.

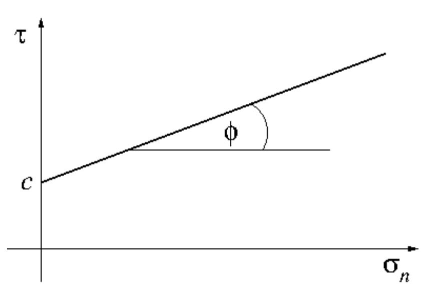


In soil mechanics, *shear strength* refers to the magnitude of the shear stress the soil can sustain. The shear strength is exceeded when the interlocking particles can no longer resist the force exerted upon them; at this point the particles slide past each other, creating a *slip plane*, as illustrated above. The slip planes cause blocks of earth to slide past to each other, leading to potential collapses in many scenarios such as retaining walls, structures with shallow foundations and slopes: see below!

The shear strength of soil depends on the interaction between the particles and not on the strength of the individual particles (it is assumed that they do not break). Shear strength has the following relationship:

$$\tau = c + \sigma_n \tan\phi$$

where τ is the shear strength and c is the *cohesion*, a frictional constant relating to the roughness of the particles. The final term, $\sigma_n \tan\phi$, describes how strength varies with normal stress σ_n (the weight of the building divided by the area of the foundation). ϕ is the *friction angle* of the soil, a constant for any particular soil. The more you press onto the interlocking particles, the more difficult it is for them to slide past each other, so increasing σ_n results in greater shear strength.



Plotting this line gives the Mohr-Coulomb failure criterion, shown above. If an engineer knows the cohesion and friction angle for a given soil, they can use the failure criterion to design structures safely: the loading condition must be below the Mohr-Coulomb line.

In practice, soil properties can be measured using a *shear box* apparatus like the one below. The soil sample is placed in the box (1), completely filling it. The box is split horizontally, so the top half can slide (shear) over the bottom half. The motor (2) is used to shear the box, with the gauge (3) measuring the induced displacment. The normal stress is adjusted by adding weights to the lever (4). A number of paired (σ_n, τ) measurements are recorded, and then the best fit straight line yields c and ϕ.

The Lego version of this experiment differs as follows

- Rather than attempting to read the shear strength directly, we suggest you instead record the motor speed (by differentiating motor position with time). A reduction in motor speed at constant power means that the torque needed to shear the box has increased. Observing the variation of motor speed at different loads shows how the shear strength increases with normal stress.
- The standard experimental procedure requires new soil samples to be used at each different load. To automate the experiment, the same sample will be used and will be agitated between runs to get it as close to its original state as possible.
- You should sit a single weight on the shear box, and lift it via a spring and a pulley, thus producing a variable normal stress. In contrast, the standard apparatus uses fixed loads that are changed between runs.
- You will use Lego for the apparatus and rice for the "soil"!

Given all these approximations, the aim of the experiment is to demonstrate that rice is a frictional material and show that it adheres, at least approximately, to the Mohr-Coulomb criterion. Accurate measurement of c and ϕ would be very difficult with unadulterated Lego equipment.